Sparse Sampling Image Reconstruction In Lissajous Beam-scanning Microscopy

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Sparse sampling takes advantage of the high information redundancy in conventional images, such that much of the essential information content can be mapped into a much smaller sized basis set by image compression. Similarly, full images can often be reconstructed from a relatively small subsampling of pixels building on this inherent redundancy, with the results varying considerably depending on the quality of the reconstruction algorithm used and the signal to noise ratio of the sampled pixels. The bottlenecks for high-speed imaging can be reduced by orders of magnitude through maximizing the inherent information content per measurement acquired by sparse sampling, rather than maximizing the sheer volume of data obtained [1]. The primary focus of the present work is centered on assessing the advantages and disadvantages of sampling patterns easily accessible with instrumentation commonly in use for beam-scanning microscopy.

Reconstructions with known ground-truth results (A) were performed for four different beam-scanning trajectories, the results of which are shown in Figure 1. Trajectories were all selected consistent with an 800 Hz frame rate with reconstructions to produce 512×512 pixels images in each frame. Given the original sampling rate of 30 Hz, these reconstructions correspond to a 27-fold increase in the frame rates through in-painting. For the random-access sampling (B), the duty cycle was assumed to be 100% with no dead time for sample repositioning and a dwell time of 50 ns was assumed for consistency with the approximate minimum dwell times achievable using the raster and Lissajous scanning approaches. This represents the theoretical limit of sparse-sampling, but in practice a 100% duty cycle cannot be implemented due to hardware limitations. The results from two different Lissajous trajectories are shown in the figure, differing in the physical hardware performing the beam-scanning. In D, the Lissajous trajectory shown in the figure was selected based on representative values for the resonant mirror period (8 kHz) and the upper bandwidth on a typical galvanometer (~800 Hz), consistent with Lissajous scanning performed using a conventional galvanometer/resonant scanner instrument. In C, it was assumed that beam-scanning was performed using a pair of resonant scan mirrors. For the interleaved raster scanning (E), the trajectories were assumed to be bidirectional (i.e., the trace and retrace recorded on separate lines) with no dead time associated with the slow-axis repositioning between lines. In-painting the unsampled pixels was performed using an in-painting algorithm designed for applicability with data sets of arbitrary dimensionality developed by Garcia. [2].

From inspection of Figure 1, it is clear that the random-access trajectory (B) results in the most reliable reconstruction among the trajectories sampled, followed by dual-resonant scanning Lissajous trajectories (C). Quantitative analysis of the errors arising in the reconstructions as a function of the effective frame rate is shown in Figure 2. Consistent with the qualitative expectations from inspection of the images in Figure 1, the random-access trajectory (rhombuses) provides the least reconstruction errors, followed by dual-resonant scanning Lissajous (triangles). The comparisons between interleaved raster scanning (squares) and galvo-resonant Lissajous scanning (circles) are mixed, with galvo-resonant providing greater reliability at higher degrees of undersampling. The performances of the different trajectories illustrated in Figure 2 are generally weighed against the practical constraints associated with beam-scanning hardware.
Using this approach, effective frame rates approaching 1 kHz can be achieved in a beam-scanning instrument by two complementary approaches. For existing instrumentation based on scanning with a resonant mirror and galvanomater pair, Lissajous trajectories generally reduce uncertainties in reconstructions relative to interleaved raster scanning. If the slow-scan galvanometer is replaced by a second resonant mirror, the quality of the reconstruction improves. The key advantages of this approach are its experimental simplicity and direct compatibility with microscopies performed using beam-scanning instrumentation [3].

References:

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Figure 1. Still frames selected from spatial-temporal in-painting based on a discrete cosine transformation for different assumed sampling trajectories. A) Groundtruth; B) Random Access; C) Dual Resonant Lissajous; D) Galvo-Resonant Lissajous; E) Raster Scanning

Figure 2. Comparison of the reconstruction error for different sampling trajectories. Squares: Raster scanning; Circles: Galvo-Resonant Lissajous; Triangles: Dual Resonant Lissajous; Rhombuses: Random Access